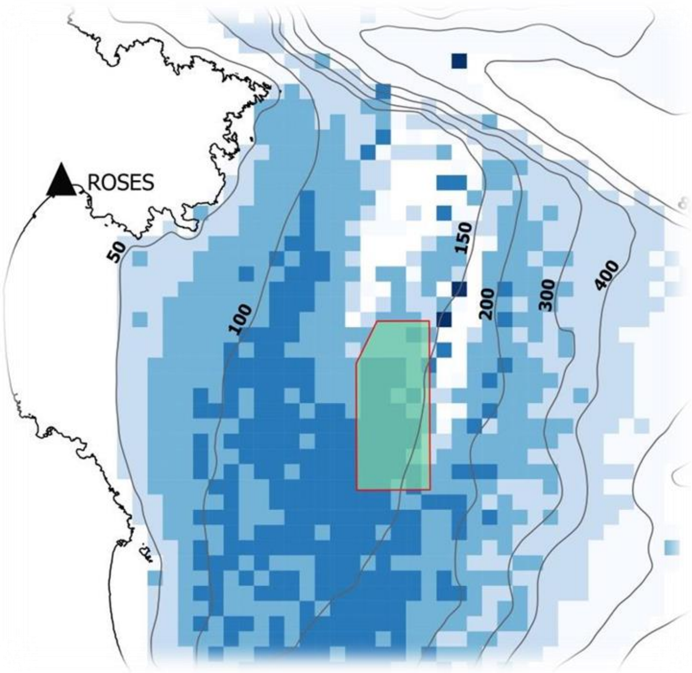
Roses' no-take marine zone effectiveness and spatiotemporal hake population assessment using GIS tools



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ABSTRACT

Marine protected areas (MPA) have been a management tool implemented both for biodiversity conservation and fisheries sustainability. Proofs for biodiversity conservation are consistent but for fisheries sustainability remain scarce. The establishment of MPA also has social consequences as it is introduced in a particular social context where conflicts might be already occurring. Co-management appears like a solution to involve all stakeholders on MPA management, minimize social conflicts derived from its establishment and therefore enhance its effectiveness. In 2013, Roses (NW Mediterranean, Catalan coast) Hake fishermen decided to establish a no-take area in front of Roses Gulf as solution for Hake catches declining trends observed over the past 25 years. Scientific organizations collaborate with fishermen in management and already demonstrated positive effects on biodiversity and biomass inside the area borders. In the present study we analyse the possible effect of the no-take zone beyond its boundaries and the presence of biomass spillover. Using GIS tools we defined analogous areas to the protected one in order to compare them over time. Data analysed was obtained by merging Vessel Monitoring System (VMS) positioning data with daily landings data in order to have geo-referenced Hake catches. Using this methodology we were able to analyse spatiotemporal Hake population behaviour and no-take zone effectiveness. Our results on hake distributions were consistent with previous studies; juveniles concentrated on the continental shelf whereas adults were found to be spread over the self and the slope. Summer-spring recruitment peak evidences were found whereas adult spawning aggregation behaviour was not recorded in our data. We found a positive spillover effect for Hake juveniles confirming the effectiveness of the no-take zone implementation. However, spillover effect was not strong enough to counteract global population declining trends and therefore more protection time will be needed to disentangle if this effect will reverse the general declining hake population trend.

INTRODUCTION

1. Marine Protected Areas and Fisheries Co-management

The establishment of Marine Protected Areas (MPA) has been a management tool implemented to enhance biodiversity and habitat conservation. Moreover, MPA have also been predicted to have a benefit on adjacent fisheries through two main factors: the emigration of adults and juvenile individuals to zones where fishing is allowed (spillover effect, Rowley 1994) and the exportation of pelagic eggs and larvae from spawning stocks inside MPA (Harmelin-Vivien et al. 2008). Besides the effects on the target species, the protection of an area from fishing can also reduce collateral effects of fishing, such as by catch, impact on benthic areas and therefore be a useful tool specially for multispecies fisheries (Hilborn et al. 2004). However, the establishment of an MPA does not guarantee by itself the accomplishment of these objectives, MPAs have to be carefully designed, monitored and evaluated in order to achieve them (Hilborn et al. 2004; Sale et al. 2005). Edgar et al. (2014), after analysing 87 MPA worldwide, defined five key factors that determine the effectiveness of an MPA: degree of fishing permitted, level of enforcement, MPA age, MPA size and presence of continuous habitat allowing fish movement across MPA boundaries. Even if just 10% of MPA analysed fulfilled the five key factors the study showed that the more factors an MPA accumulates the better its performance is.

While there are scientific evidences proving that the establishment of MPA enhance habitat conservation, biodiversity and biomass within its boundaries, proves regarding the effect of MPA on fisheries yields remain scarce (Roberts et al. 2001; Sale et al. 2005). In the Mediterranean Harmelin-Vivien et al. (2008) demonstrated the existence of fish spillover in six MPA in the Western Mediterranean by proving a decline of fish abundance from inside to outside the protected areas. However, they estimated that spillover was limited to hundreds of meters around MPA and conclude that more information is needed concerning fishes home range and spatial behaviour in order to design MPA with a significant effect on adjacent fisheries (Harmelin-Vivien et al. 2008). Complementary to the previous study, Goñi et al. (2008) proved CPUA rises and fishing effort concentrations of artisanal fleet in areas around the same MPA studied by Harmelin-Vivien et al. (2008) as a consequence of MPA commercial fish spillover.

Even if the aims underlying the creation of MPA are in most cases biological or sustainability reasons, the establishment of MPA does not only have biological but also social consequences. Some studies have highlighted that the creation of protected areas have also negative social consequences such as the displacement of indigenous communities or artisanal fishers in favour of biodiversity conservation and touristic MPA uses (Colchester 2004; Christie 2004). MPA are introduced in places with particular political, social and economic contexts that might have already conflicts going on, the creation of an MPA will somehow destabilize the community in which it is created (Chuenpagdee et al. 2013). As an example, Himes (2003) described the case of two MPA designed for fishing conservation in Sicily where the lack of involvement of the community was one of the major impediment for MPAs effectiveness. In this case fishermen were not well informed about MPA characteristics, not involved in its decision making and MPAs were not well enforced against outer illegal fishing practices. As a consequence local artisanal fishermen did not felt that their interests were represented by the MPA, some disagreed with it, mistrust towards managers existed and even some illegal practices took place by the fishermen.

Therefore, it seems clear that involving all stakeholders in the definition and management of an MPA is a key factor not only to reduce the social conflicts derived from its establishment but also to enhance its effectiveness and avoid what is called “paper parks” (Jones and Burgess 2005; Nursey-Braya and Rist 2009; Rife et al. 2013). By linking social and scientific/conservationist goals, co-management appears like the appropriate framework for these purposes (Carlsson and Berkes 2005; Jones and Burgess 2005; Nursey-Braya and Rist 2009). Co-management is defined as the sharing responsibility and authority between the state and resource-users (local community) (Carlsson and Berkes 2005). As a consequence of the complexity of these two parts it often involves collaboration between a variety of stakeholders such as different government organizations, non-governmental organizations, research organizations, private enterprises and civil society (Carlsson and Berkes 2005).

In the European context, the Common Fisheries Policy system of decision and policy making has been considered to have failed in the conservation of fisheries resources in UE, with the disconnection between politicians, scientists and fishermen in the centre of the causes (Daw and Gray 2005). Therefore, EU fisheries policy started recognising the need to involve resource users in management and consequently a shift towards co-management of EU fishery policy (Daw and Gray 2005; Linke and Bruckmeier 2015; Symes et al. 2003). The European Common Fisheries Policy created the structures of RACs (Regional Advisory Council) and FLAGs (Fishery Local Action Groups) as a measure to involve stakeholders and have a better representation of territory heterogeneity in fishery policy making (Linke and Bruckmeier 2015). However, the social, historical and cultural differences of the European regions make necessary a closer look to territorial idiosyncrasy in order to adapt these co-management measures (Franquesa 2004; Symes et al. 2003). In the Mediterranean, fishermen organisations have been maintained along time as the case of “confraries” in the Spanish coast (Franquesa 2004) and of “prud’homies” in the French zone (Symes et al. 2003). These organizations constitute by themselves a strong stakeholder for co-management that has to be taken into account when approaching a co-management fishery policy in these zones.

In this study we analyse the effectiveness of a self/co-management no-take marine zone establishment carried out by the local Fishermen Association (“confraria”) of Roses (Catalan Coast, NW Mediterranean) with the aim of ensuring a long term sustainability of hake (*Merluccius merluccius*) population and fishery. This case is an example of strong resource users implication in fishery management using a protected area specially designed for fishery recovery purposes.

2. Roses Hake Fisheries and the Protection Plan

Roses is an important fishing port in the Catalan coast in terms of catches and economic importance. Total Roses catches in 2016 were 1504 tonnes representing the 5.3% of catches in the Catalan region which in economic terms represented 8.8 milions € and the 8.6% of Catalan 2016 fishery incomes. Roses’ fishery is multispecific, catching around 110 different commercial species. In the port, Hake represents the second species in economic importance (only surpassed by the red shrimp *Aristeus antennatus*) representing the 13.11% of the total port fishing incomes in 2016. Hake is mainly catched with trawling vessels (around 95% of 2016 hake catches) although longlines and gillnets are also used.

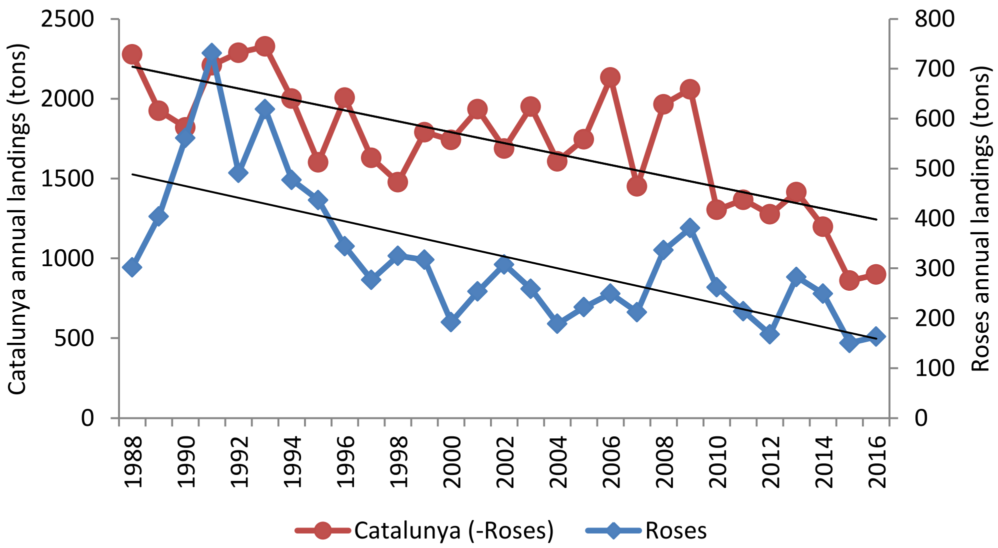
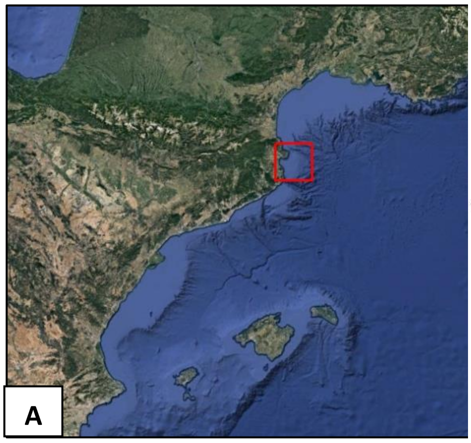


Figure 1. Time series of annual landings of *Merluccius merluccius* in the Catalan coast (excluding Roses Port, blue) and in Roses port (red). Linear tendencies are represented by lines.

Over the past 25 years Catalonia and Roses Hake catches have experienced a declining trend (Figure 1). Even if the population has a natural fluctuation regulated by the interaction between intrinsic biological factors interacting with environment, it can be clearly seen the declining tendency of the global time series (Figure 1). In this context Roses Fishermen Association took the initiative of start a protection plan for Hake in order to revert this tendency. Unilaterally, in 2013 (February to October) fishermen decided to establish a no-take marine area in front of Roses port, where there were supposed to be a nursery ground for Hake juveniles (Figure 2). Since February of 2014 this area is permanently closed to all fisheries including longlines and gillnets. The area had 51km2 and was placed on the continental shelf at 130-150m depth in a fishery ground where there was trawling activity. All port trawling fleet was involved in the measure and control, surveillance and punishments were managed by Roses Fishermen Organization.



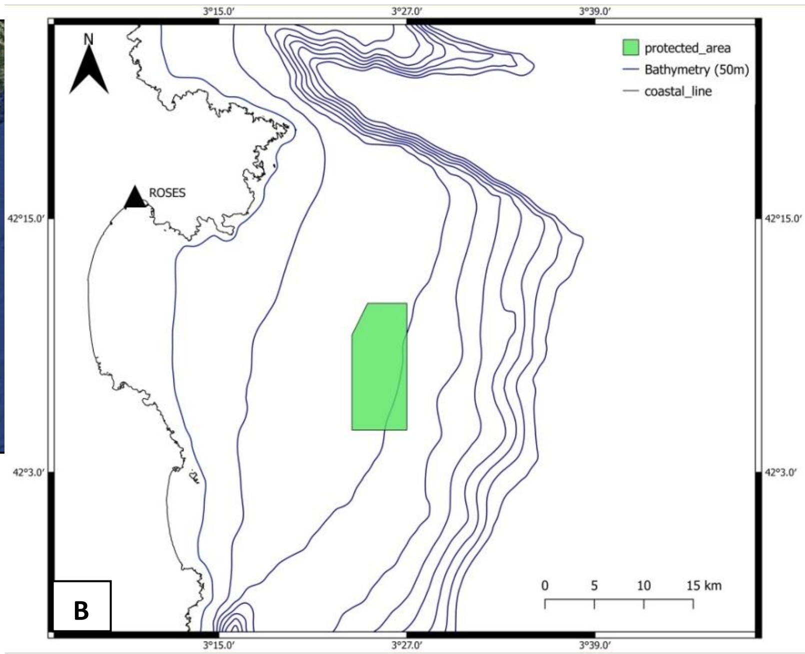


Figure 2. **(A)** Geographical situation of the Roses Gulf. **(B)** Situation of the protected area established by Roses Fishermen Association. Bathymetry intervals of 50m represented by blue lines.

After one year of protection Roses Fishermen Organization contacted scientific organizations (Institut de Ciències del Mar, CISC) in order to collaborate in the management plan, when we can consider that co-management started. A first scientific study was carried out from March 2015 to March 2016 analysing the effects of the management plan within the boundaries of the protected area (Pla Pilot de seguiment biològic del lluç (*Merluccius merluccius*) en els caladors del port de Roses). There were proofs of a higher abundance, biomass and biodiversity of the whole community inside the protected area compared with an analogous area where fishing activity continued normally. The effect was evidenced both on economic valuable species and on benthic communities not commercially exploited (Balcells et al. 2016; Recasens et al. 2016).

In the present study we will analyse the consequences for Roses hake fishery of the establishment of the protected area, that is, analyse if the effect of the increased biomass, abundance and biodiversity within the protected area boundaries has an effect outside it (spillover effect) enhancing hake fishery productivity. To achieve this goal we will combine VMS (Vessel Monitoring System) and daily vessel landings data. As a novel methodology in this kind of studies, analysing its potential turns to be an objective of this work by itself. Therefore we have two main objectives:

a. Explore the potential of VMS/GIS tools to spatially and temporally characterize hake populations.
b. Analyse the effect of the establishment of a fishing protected area on the hake Roses fishery.

MATERIAL AND METHODS

1. Area of Study and Areas Definition

Our experimental design was based on the definition of analogous areas to the protected one (IN1) situated on its surroundings, trying to cover three different habitats of hake: continental shelf (100-130m depth), beginning of the continental slope (175-275m depth) and the habitat in between (130-175m depth) (Figure 3). We conserved the areas that previous studies were based on (protected and comparison area, Balcells et al. 2016; Recasens et al. 2016) and then define four more areas for this study (shelf and slope). Criteria used to define the areas were (in order of priority):

1. Same surface as the protected area (51km2)
2. Cover zones where there was fishing activity
3. Areas in the same habitat must be at the same depth range
4. Northern areas parallel to the protected one and southern areas parallel to the comparison one
5. As close as possible to the protected area
6. Maintain the same shape as the protected area

Following this criteria we did not define areas on the northern part of the protected area as no fishing activity was registered on that zone (Figure 3) and the shape of areas P1 and S1 had to be adjusted for the same reason. Area P2 shape had to be modified in order to be at the same depth range than its equivalent area (P1) and area S1 had to be further from the Comparison area (C2) for the same reason. With this experimental design we cover hake different habitats in order to study spatial variations and possible differences of the biomass in the protected area in comparison with areas where fishing is allowed to elucidate the possible spillover effect.

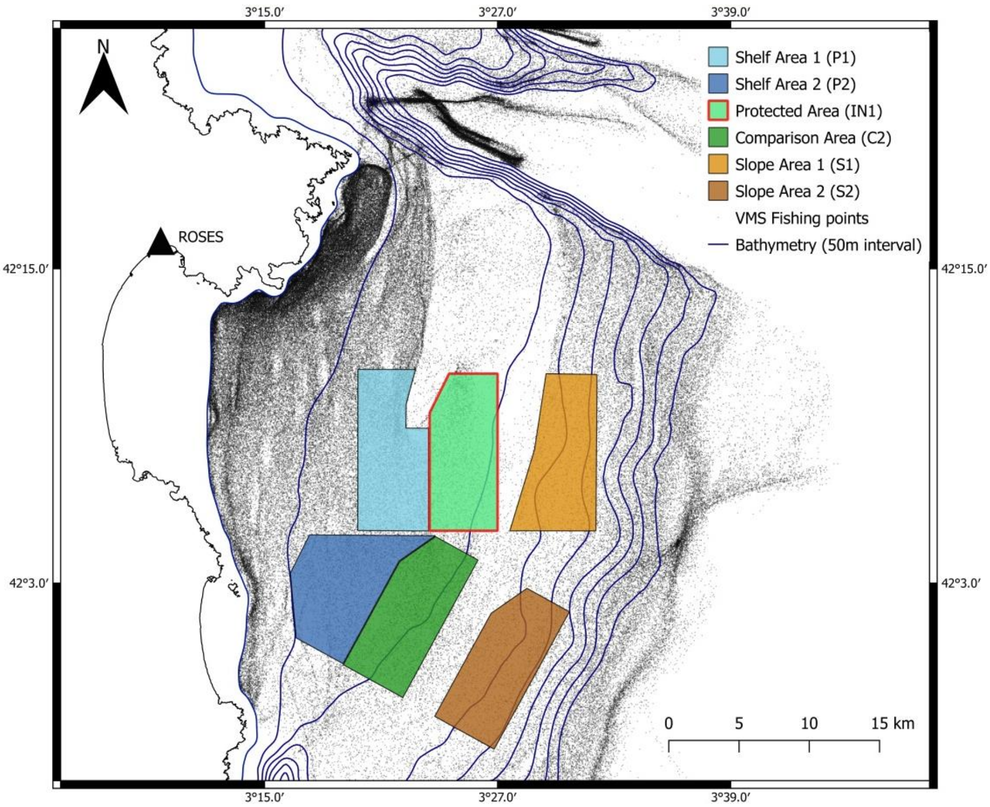


Figure 3. Situation of the defined study areas, bathymetry (50m lines from 50 to 450m depth) and VMS fishing points (grey dots).

2. Obtaining Geographical Data

In order to assess hake population dynamics in the defined areas, geo-referenced catches data is needed. In our study we combined Vessel Monitoring System (VMS) and daily vessel landings data to achieve this objective and analyse possible differences either in space or time of hake population.

a. Fisheries data

As fishing effort control measure, Mediterranean Spanish trawling fleet is just allowed to fish five days a week and a maximum of 12h per day (Real Decreto 144/1999) and therefore vessels return to the same port (port base) every day. There landings are registered, aggregated by the local fisherman associations and sent to the regional administration (Direcció General de Pesca, Generalitat de Catalunya) (Figure 4).

Fishing records contain everyday catches from each vessel that, in the case of hake, are classified in different commercial sizes classes: Hake 1 (>48cm), Hake 2 (38-48cm), Hake 3 (30-38cm), Hake 4 (25-30cm) and Hake 5 (20-25cm). Minimum legal catch size for hake is 20 cm (EC 2006). Hake 1 individuals are not found now in the trawl fishery. Hake 2 are the biggest catched hakes and would represent adult fishes. Hake 5 are juvenile fishes and represent the fishery recruitment fraction. We have to take into account that, as we are just using commercial landings data, we do not have information regarding non-commercial hake size classes, the smallest ones, despite their importance for hake population dynamics. Therefore, our best approximation to population recruitment will be Hake 5 class, which correspond to individuals of 1-2 years.

b. Vessel Monitoring System data

Vessel Monitoring System (VMS) was first introduced in the UE in 1997 when the European Commission introduced legislation to monitor European fishing vessels using satellite-based VMS (EC 1997). Since January 2000, fishing vessels >24m were required to transmit their position every 2h. The regulation has been amended various times including other vessels sizes and variables recorded and finally (EC 2003), from 2006 vessels >15m were required to transmit position, vessel speed and course (Gerritsen and Lordan 2011). European Commission directives were assimilated by Spanish legislation in 2003 (Orden APA/3660/2003) and modified in 2008 (Orden ARM/3238/2008).

Vessels send their position, speed and course to the satellite that send them to a receiving station on land which, in turn send them to the corresponding administration in each country, where data are processed and used to control fishing activities (Figure 4). In the case of Spain data is sent to the “Centro de Seguimiento de Pesca (Ministerio de Agricultura y Pesca)”. We have required and obtained data for all Roses trawling fleet from 2006 to 2016. It is important to notice that VMS data do not indicate whether vessels are fishing, travelling or inactive, therefore posterior data treatment will be needed to select fishing activity.

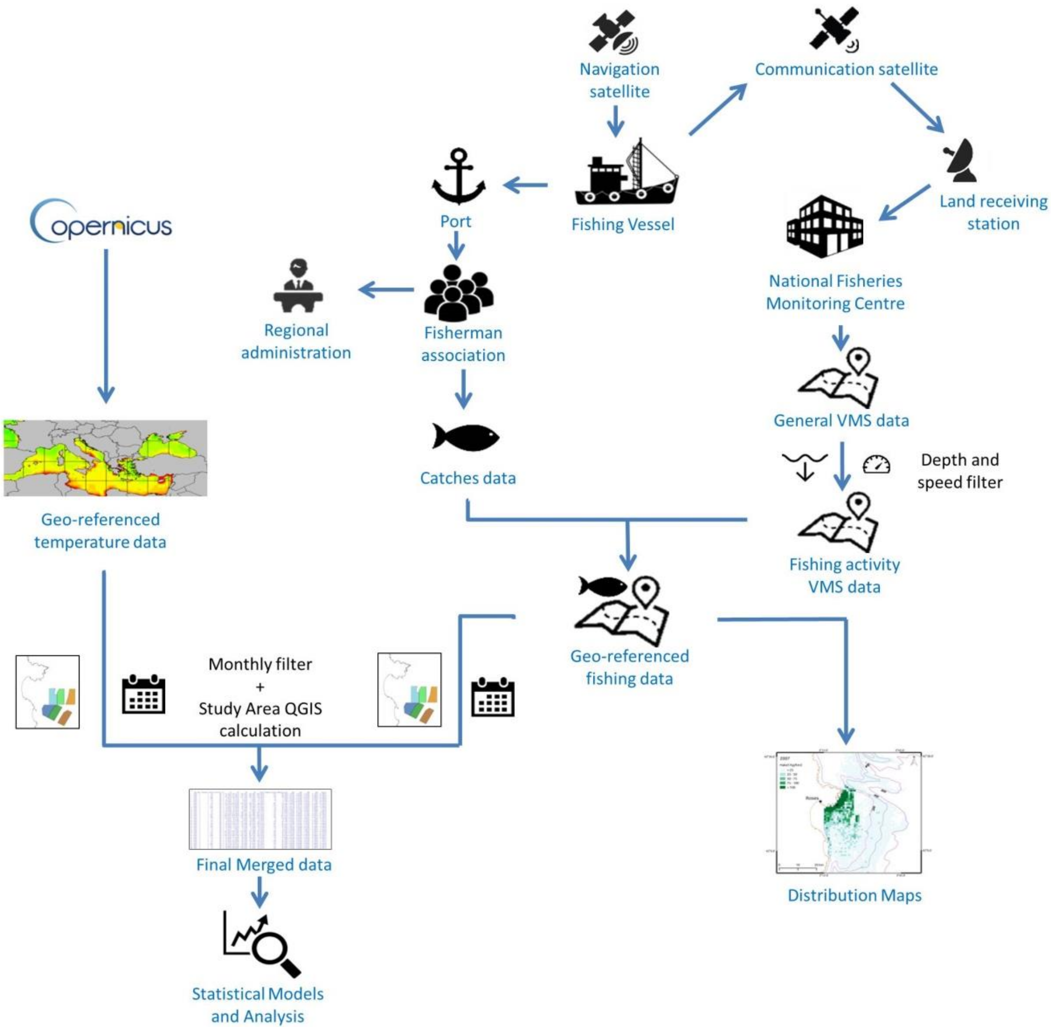


Figure 4. Material and methods summary. Data process to obtain Distribution maps and be able to run statistical models. Different data sources are shown: VMS, landings and environmental data.

In order to select positioning data for fishing activities and discard data from other vessel activities, speed and spatial filters were applied. We applied a speed filter between 1.5 and 5 knots that include speed peaks of vessel trawling activity and a depth filter to discard points at shallower depths than 50m where trawling is not allowed in Spanish Mediterranean coast (Real Decreto 1440/1999).

c. Data merging and GIS treatment

Once we had VMS (filtered by speed and depth) and fishing data for the same period we merged them by date and vessel in order to geo-reference fishing catches. Daily catches were assigned equally to all fishing positions for the same day and vessel. Even if this implies the assumption that all catches in a day are uniformly distributed and this can introduce an error in our data, we consider that bias is attenuated for two reasons: this bias is maintained over time for all data and that as a consequence of the accumulation of data at the same zone, possible spatial patters will be appreciated. Moreover, there are studies demonstrating that this methodology does not introduce big bias when compared with positioned catches data collected in-situ (Gerritsen and Lordan 2011).

Merged data was introduced in QGIS software (QGIS Development Q. D. Team, 2017) in order to be geographically analysed. Following our experimental design, we first filtered all fishing data by month and then calculate total hake catches and fishing time for each area defined (Figure 4). Therefore, a total of 792 observations were obtained (12months x 11years x 6Areas). Due to the fishery closure on February, the establishment of the protected area and the distribution of fishing activity, in some months and areas data were not available (no fishing activity) and finally we had a total of 757 month/area observations with actual data.

d. Environmental data

In order to control possible effects of environmental factors on hake distribution and abundance, temperature data was included in our analysis. Data were obtained from Copernicus Marine Monitoring Service using IBI_005_002 monthly mean Bottom Temperature for years 2006-2014. For 2015 and 2016 years, we used IBI_005_001_b daily water potential temperature at 109m, 130m and 186m depth for shelf (P1/P2), IN1/C2 and slope (S1/S2) areas respectively. Temperature data were also introduced in QGIS software (Q. D. Team 2017) to extract the mean temperature in each study area. For 2015 and 2016 years, monthly mean had to be previously calculated.

3. Data Analysis

Once hake catches and fishing time for each study area were calculated using QGIS software we introduced data to R software (R Develompment Core Team 2013) for further statistical analysis. The first step was to calculate Catches Per Unit Effort (CPUE) to delete spatial and temporal variations of hake catches due to the distribution of fishing effort, e.g. in shelf areas fishing effort might be higher than in other areas because of their proximity to Roses port. Therefore, from now on, all catches data analysed will be described with kilograms per hour (kg/h). As one of our objectives is to describe spatiotemporal hake population dynamics, another reason to use CPUE is because its closer approach to fish abundance than raw catches data even if these variables are not exactly proportional (Harley et al. 2001).

Adult and juvenile European hake have different spatiotemporal behaviour (Recasens et al. 1998). In a general overview, we can say that while juveniles are mainly distributed on the continental shelf (50-200m), adults are found in a wider depth range (50-450m) and concentrate in the continental slope during spawning seasons (Recasens et al. 1998). This behaviour makes necessary a different analysis for adults and juvenile stages in our study. We took Hake 2 size class as hake adults and Hake 5 size class as hake juveniles. We did not include Hake 3 and 4 size classes in our analysis as during hake catches sorting made by fishermen these are the classes more easily confused and this could introduce a bias in our data. We kept Total Catches variable in order to analyse the general population trends. Therefore, final variables analysed in our models were Hake Total catches, Hake 2 and Hake 5, all of them in CPUE (kg/h).

a. Data pre-processing

We had VMS and therefore geo-referenced catches data from 2006 to 2016 years. This is 7 years without the protected area (2006-2012) and 4 years since the protected area was established (2013-2016). As one of our main aims was to compare the system before and after the protected area was established, we considered that in order to statistically analyse this factor we had to have the same amount of years data before and after the protection started. Therefore, we did not include in the analysis data from 2006 to 2009 and we carried out the analysis with data from 2010 to 2012 as before the protection system and 2014 to 2016 data after the protection system. We did not include 2013 data because protected area was not permanently closed during this year. The main objective after that was to avoid effects in our results caused by the higher variability of the non-protection period caused by its longer time series.

Hake populations have a natural fluctuation dynamics due to intrinsic biological factors in interaction with environment (Figure 1). As we were not interested in these dynamics but in variations of hake population behaviour underlying them, we normalized data aiming at remove the effect of natural population fluctuations. We used MIN-MAX normalization method (Patro and Sahu 2015) taking specific Min and Max data for each year studied in order to eliminate inter-annual variability:

$$Xn = \frac{x - (yearMIN)}{(yearMAX) - (yearMIN)}$$

Xn = MIN-MAX normalized data
yearMIN = minimum value of the year
yearMAX = maximum value of the year

b. Statistical Models

Statistic data analyses were carried out using ANCOVA models. We defined three factors according to our objectives:

- Protection: evaluating the effect of the protected area establishment. 2010-2012 = Before the Protection (BP) and 2014-2016 = After the Protection (AP).
- Area: evaluating the spatial distribution of hake. 6 levels corresponding to the 6 areas defined.
- Quarter: evaluating the intra-annual variability. January-March (1st), April-June (2nd), July-September (3rd) and October-December (4th).

Interactions between factors were also included in models. Temperature data were also normalized using MIN-MAX procedure and used as covariate in models, so as to control its possible effect on hake population. Consequently, we ran models with three categorical factors, their interactions and one covariate each, using MIN-MAX normalized Total Hake CPUE, Hake 2 CPUE and Hake 5 CPUE as dependent variables.

4. Distribution Maps

Besides statistical analysis of our experimental design, we wanted to graphically analyse hake distribution within all area where Roses fisherman operate. We used merged data to elaborate maps and see how fishing and therefore hake is distributed in the space.

We joined geo referenced catches (kg) and effort (h) data (from 2010 to 2016) in 1km^2 squares and calculate CPUE (kg/h) afterwards for each square. Variables used were the same as for statistical models: Hake Total Catches, Hake 2 and Hake 5. We used again CPUE in order to delete effects of the fishing effort distribution and have a closer approach to hake abundances than we would have with catches data alone (kg).

RESULTS

In a general overview of our model results we can say that all studied factors (Area, Protection and Quarter) showed significant effects on all variables (Total Hake, Hake 2 and Hake 5) (see Tables 1, 2, 3). Moreover, there were statistically significant interactions of the factors, Protection + Quarter for Total Hake and Hake 5 and Area + Protection for Hake 2. These general results suggest that spatial and temporal differences and protection effects exist in the hake population studied. Temperature showed only a significant effect on Total Hake (Table 1).

Table 1. ANCOVA models results with Total Hake (min-max normalized) as dependent variable**.**

TOTAL HAKE	Df	Sum Sq	Mean Sq	F-value	p-value
Area	5	1.366	0.2733	7.331	1.48e-06***
Protection	1	1.271	12.707	34.086	1.19e-08***
Quarter	3	3.147	10.489	28.138	2.40e-16***
Temperature	1	0.246	0.2460	6.600	0.0106*
Area:Protection	5	0.296	0.0592	1.588	0.1627
Area:Quarter	15	0.667	0.0444	1.192	0.2753
Protection:Quarter	3	1.517	0.5056	13.563	2.14e-08***
Area:Protection:Quarter	15	0.302	0.0201	0.539	0.9179
Residuals	355	13.234	0.0373		

Table 2. ANCOVA models results with Hake 2 (min-max normalized) as dependent variable.

HAKE 2	Df	Sum Sq	Mean Sq	F-value	p-value
Area	5	1.446	0.2892	6.851	4.05e-06***
Protection	1	0.376	0.3765	8.918	0.003020**
Quarter	3	0.869	0.2898	6.865	0.000166***
Temperature	1	0.016	0.0157	0.372	0.542504
Area:Protection	5	0.540	0.1081	2.560	0.027144*
Area:Quarter	15	0.638	0.0425	1.008	0.446011
Protection:Quarter	3	0.245	0.0818	1.937	0.123176
Area:Protection:Quarter	15	0.908	0.0605	1.434	0.128794
Residuals	355	14.986	0.0422		

Table 3. ANCOVA models results with Hake 5 (min-max normalized) as dependent variable.					
HAKE 5	Df	Sum Sq	Mean Sq	F-value	p-value
Area	5	3.101	0.6201	17.253	2.74e-15***
Protection	1	0.453	0.4532	12.610	0.000435***
Quarter	3	2.485	0.8284	23.047	1.18e-13***
Temperature	1	0.000	0.0003	0.007	0.931138
Area:Protection	5	0.069	0.0138	0.384	0.859395
Area:Quarter	15	0.865	0.0577	1.605	0.070136
Protection:Quarter	3	1.082	0.3608	10.037	2.30e-06***
Area:Protection:Quarter	15	0.283	0.0189	0.525	0.926583
Residuals	355	12.760	0.0359		

1. Spatial Roses Hake Fishery Characterization

a. Effect of area in models

As explained before, the factor Area was highly significant for all variables studied indicating that hake is not homogenously distributed in the space (Tables 1, 2, 3). The analysis of the whole population (Total Hake) show a higher biomass of hake in the continental shelf, either in the middle of it (Areas P1 and P2) or closer to the slope (Areas IN1* and C2) (Figure 5). Areas at the same habitat had similar results for shelf (P1, P2) and slope (S1,S2) whereas for the habitat in between it seems that the southern area (C2) has a higher density of hake than its northern analogous (IN1*, protected area) (Figure 5).

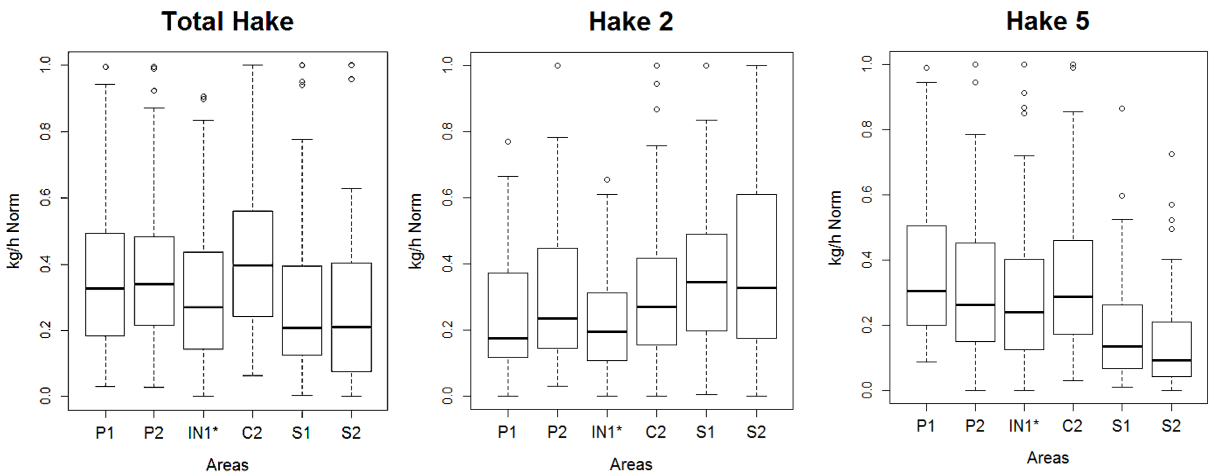


Figure 5. Biomasses (kg/h Min-Max normalized) of Total Hake, Hake 2 and Hake 5 by study areas.

Adult individuals (Hake 2) showed higher yields on the slope habitat (S1, S2) than in the shelf zones (P1, P2, IN1*, C2) (Figure 5). In the shelf Hake 2 had a tendency to have a higher biomasses in southern areas (P2, C2) compared to their northern homologous (P1, IN1*). On the other hand we had juvenile individuals (Hake 5) that had an opposite distribution to Hake 2 (Figure 5). Hake 5 showed higher biomasses on shelf habitats (P1, P2, IN1*, C2) compared with the slope habitat (S1, S2). Although Hake 5 and Total Hake had similar distributions, differences between areas were higher for Hake 5 than for Total Hake.

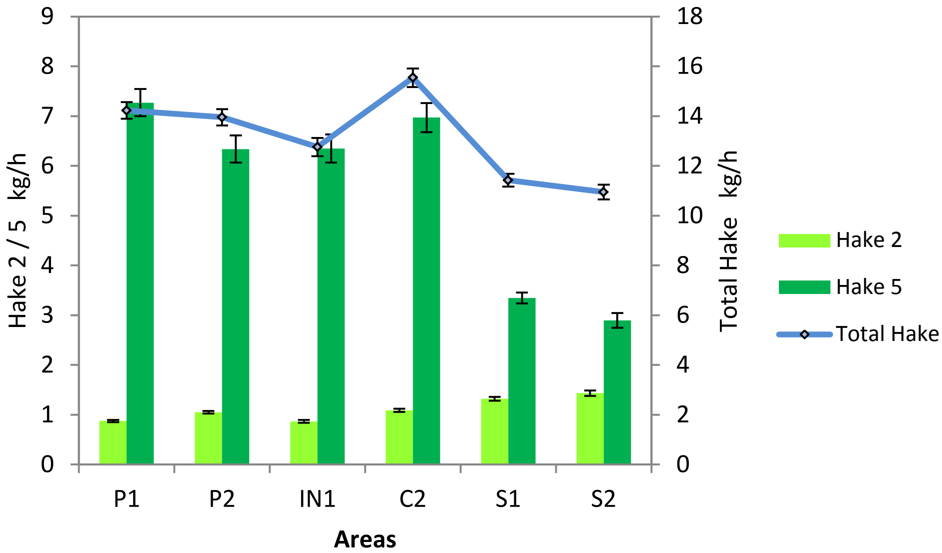


Figure 6. Biomasses (kg/h) of Total Hake, Hake 2 and Hake 5 by study areas.

Once we compare data from variables expressed in non-normalized kg/h we can appreciate the real magnitude of the yield differences between areas. Hake 5 has yields between 3 and 7 times higher than Hake 2 (Figure 6, table 4), which represents an important fraction of the global hake population (Table 4). It can be observed that the main difference found is the reduction of Hake 5 biomasses in the slope habitat and that the differences found in Hake 2 are much less important (Figure 6, Table 4). Therefore we can say that in a population level, Hake 2 has similar biomasses in all areas (with a trend to increase in slope zones) and that Hake 5 is the size class that determines the changes in Hake population structure comparing different areas with a marked reduction in slope zones.

Table 4. Mean (kg/h) and Standard Error for the different studied variables dvided by Area.

	Total Hake		Hake2		Hake 5	
	Mean	Std Error	Mean	Std Error	Mean	Std Error
P1	14,22	0,34	0,88	0,02	7,27	0,27
P2	13,95	0,33	1,05	0,03	6,34	0,27
IN1	12,76	0,37	0,87	0,03	6,35	0,28
C2	15,54	0,37	1,09	0,03	6,97	0,29
S1	11,42	0,26	1,32	0,04	3,34	0,11
S2	10,94	0,29	1,43	0,06	2,90	0,15

b. Distribution maps

The significant spatial variability found with experimental areas analysis can be observed on the distribution maps we elaborated (Figure 7). Total Hake catches (Figure 7, A) have a similar distribution as Hake 5 (Figure 7, B) with relatively high yields until 400-500m depth with a wide distribution over the continental shelf. Higher concentrations were found in the middle of the shelf between 100-200m depth in both cases. Thus, with distribution maps results we can also perceive a high influence of Hake 5 on Hake Total catches. It can be observed a zone with no data/catches north the protected area which corresponds to a rocky ground where trawling vessels cannot fish.

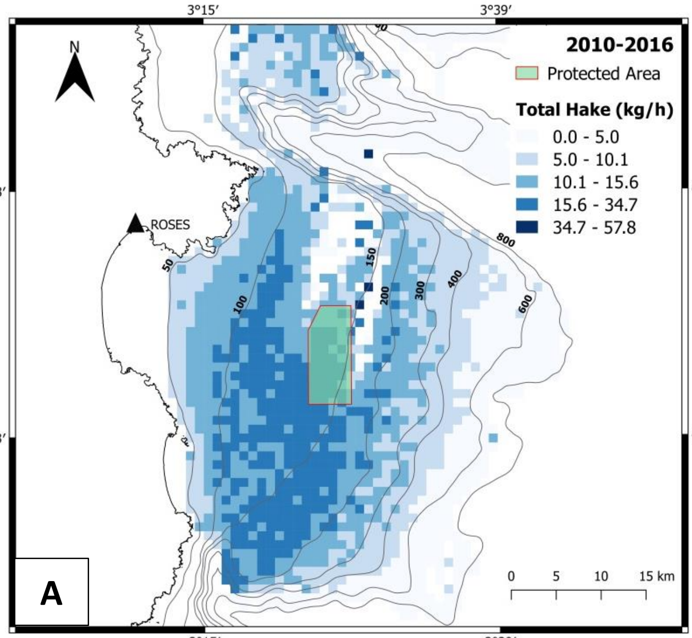
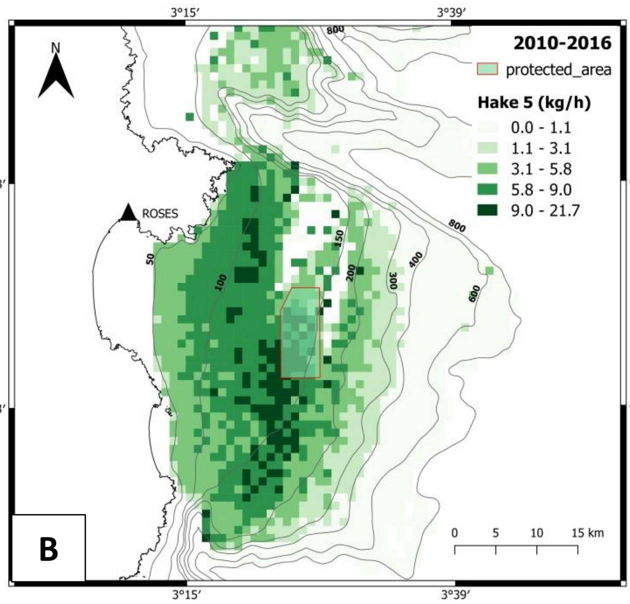
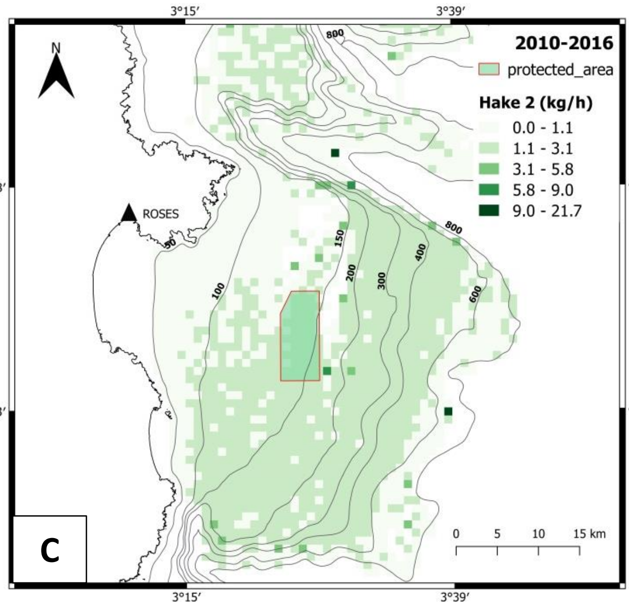


Figure 7. Yield distribution maps for Hake Total Catches (A), Hake 5 (B) and Hake 2 (C). Data used is from 2010 to 2016 years and expressed in kg/h.km^2.





Adult distribution (Figure 7, C) also shows the same results as for experimental areas analysis. It can be noticed that Hake 2 yields are lower than juvenile ones. Distribution map also shows an opposite trend compared to Hake 5. Hake 2 is mainly distributed at depths between 150 and 600m corresponding to the shelf break although there are some shallower areas (until 100m depth) that also contain Hake 2 individuals.

2. Seasonal Roses Hake Fishery Characterization

The seasonal factor (quarter) was also highly significant for all variables (Tables 1, 2, 3). Total Hake results showed the higher biomasses during the third and fourth quarters (July-December) and the lowest during the second (April-June) (Figure 8, Table 5). Hake 2 had a descendant trend from the first to the third quarter (January-September) and a slightly recover during the fourth (October-December) reaching similar values found on second quarter (Figure 8). Finally, for Hake 5 we found the lowest values on the first half of the year that reached their maximum on the third quarter. At the end of the year (4th quarter) biomasses had medium values (Figure 8).

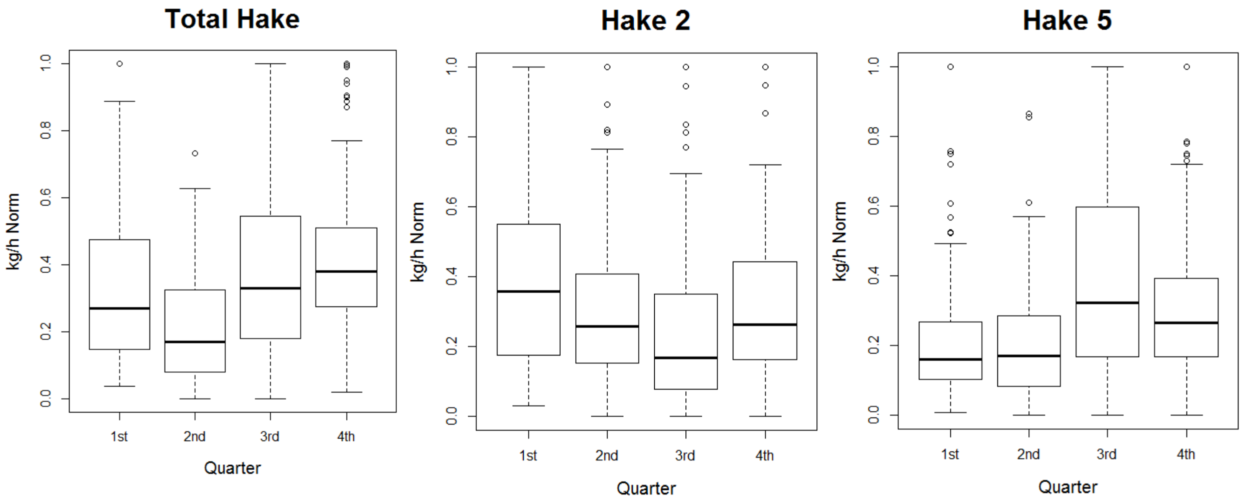


Figure 8. Biomasses (kg/h Min-Max normalized) of Total Hake, Hake 2 and Hake 5 by seasons.

Comparing data in kg/h between variables it can be observed, similarly to the spatial distribution comparisons, that the main differences in population seasonal fluctuations are highly influenced by Hake 5 variability (Figure 9, Table 5). Although Hake 2 has significant biomasses differences throughout the year Hake 5 variations are more important and determine substantially global population trends (Table 5).

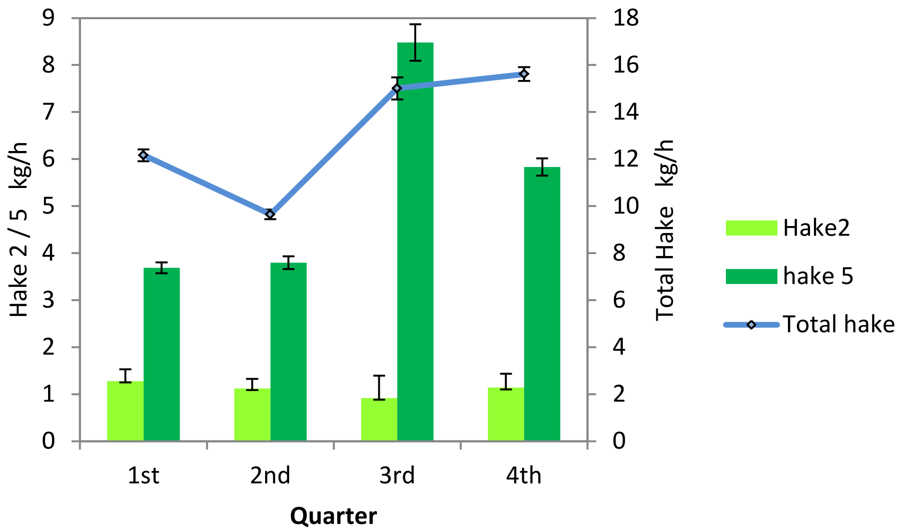


Figure 9. Biomasses (kg/h) of Total Hake, Hake 2, Hake 5 by seasons.

Table 5. Mean (kg/h) and Standard Error for the different studied variables dvided by Quarter.

	Total Hake		**Hake2**		**Hake 5**	
	Mean	Std Error	Mean	Std Error	Mean	Std Error
1st	12,16	0,25	1,28	0,03	3,69	0,12
2nd	9,64	0,21	1,12	0,04	3,80	0,13
3rd	15,01	0,47	0,92	0,04	8,48	0,39
4th	15,62	0,30	1,14	0,04	5,83	0,18

3. Protected Area Effect

The establishment of the protected area had a significant effect for all variables studied (Tables 1, 2, 3). All variables had the same trend towards higher yields during the years that the protected zone was established (Figure 10).

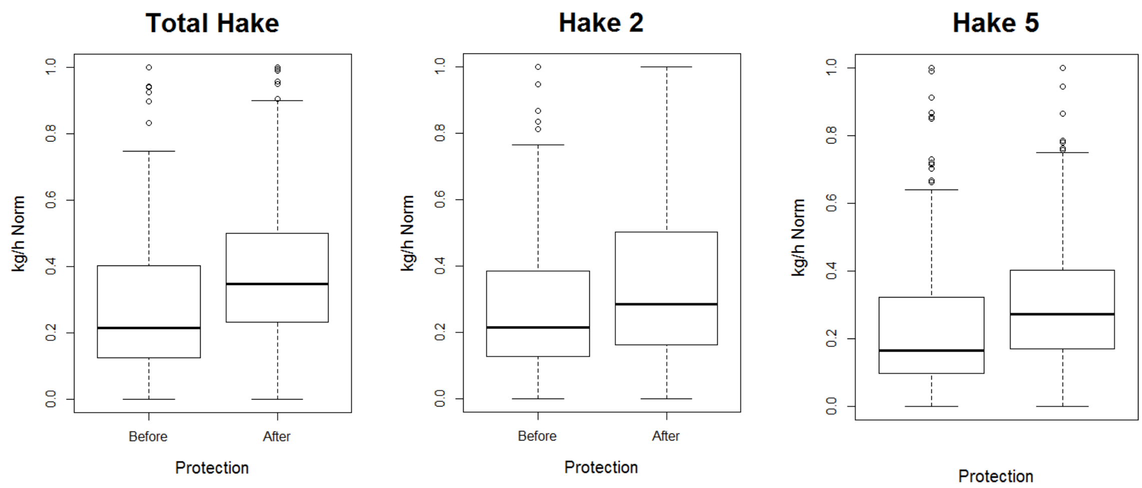


Figure 10. Biomasses (kg/h Min-Max normalized) of Total Hake, Hake 2 and Hake 5 by protection State.

Differences in kg/h observed before and after the protection are less important than for the other two factors analysed (Figure 11, Table 6). However, Hake 5 is still the size class where more variation can be observed, probably affecting Total Hake trends to a more extent than Hake 2 (Figure 11, Table 6). All variables had a tendency to have lower values after the protection.

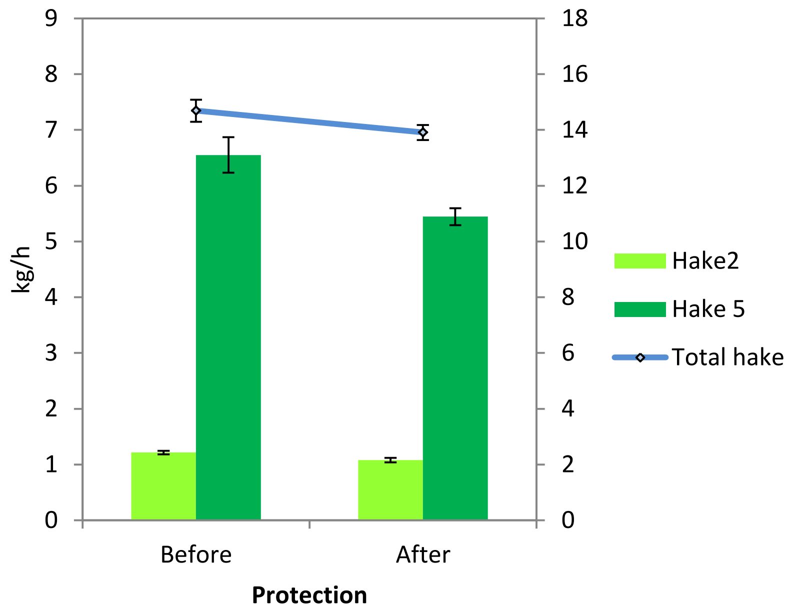


Figure 11. Biomasses (kg/h) of Total Hake, Hake 2, Hake 5 by protection state.

Table 6. Mean (kg/h) and Standard Error for the different studied variables dvided by Protection State.						
	Total Hake		Hake2		Hake 5	
	Mean	Std Error	Mean	Std Error	Mean	Std Error
NP	14,69	0,40	1,21	0,03	6,55	0,32
P	13,91	0,27	1,08	0,04	5,45	0,15

4. Interaction Terms

In our model results there were three significant interactions between factors. Firstly, Protection + Quarter had significance for Total Hake (Table 1) and Hake 5 (Table 3) with similar tendencies for both. This indicates that the seasonality of hake population was different before and after the protection started. The yields along the year of Total Hake and Hake 5 become more stable for the period where the protection was established. It can be observed (Figure 12) that after the beginning of the protection, yields of the first half of the year and the last quarter increase whereas for the third quarter (the highest before the protection) decreases, softening the seasonal differences of hake yields (Figure 12).

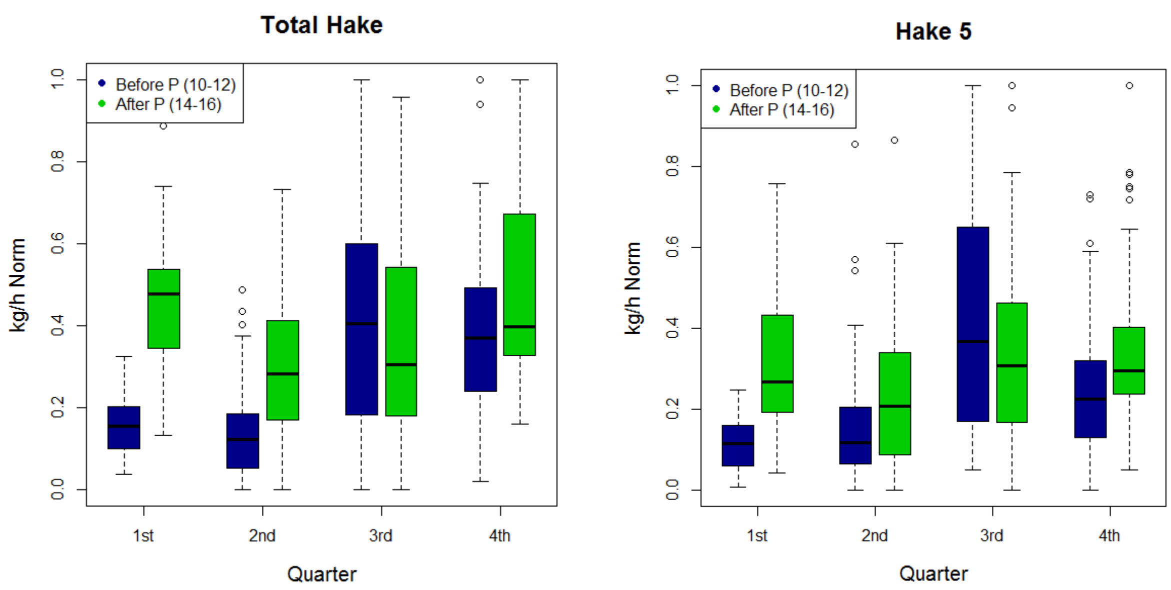


Figure 12. Total Hake and Hake 5 biomasses (kg/h Min-Max normalized) by season and protection State.

Secondly, the third interaction concerned Hake 2, where the factors Area and Protection interact significantly (Table 2). This interaction reflects that the spatial distribution of Hake 2 changed after the protected zone was established. We can observe (Figure 13) that before the protection Hake 2 had similar biomasses in shelf areas (P1, P2, IN1, C2) that were lower than the ones observed on slope areas (S1,S2), where adult Hakes were more abundant. After the protection biomasses grew especially for P1, P2, C2 and S2 areas, maintaining its values for S1. These results show a more homogeneous spatial distribution of Hake 2 after the protection started.

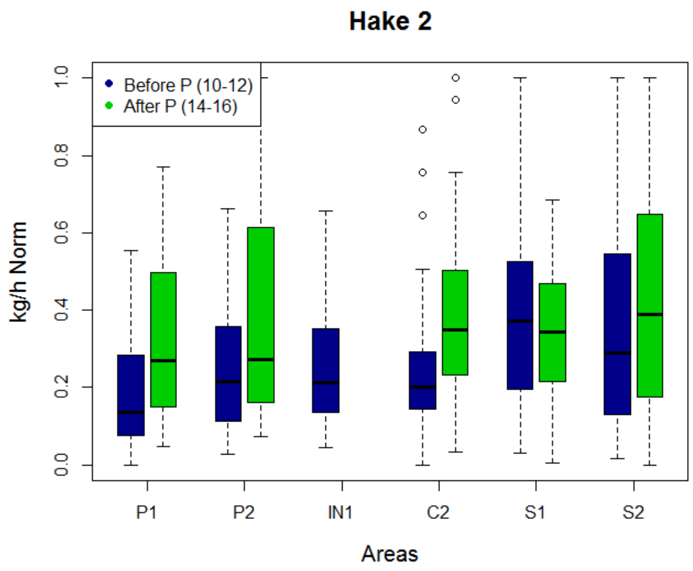


Figure 13. Hake 2 biomasses (kg/h Min-Max normalized) by area and protection state. IN1 after the protection does not appear due to the lack of VMS data for this zone and period.

DISCUSSION

The analysis of geo-referenced catches data in this study highlighted the spatiotemporal behaviour of the Hake population analysed showing significant differences between the studied areas and quarters throughout the year. Our results also showed an effect of the establishment of the no-take area with increased yields for the period after the protection started. After the analysis, it can be clearly noticed the usefulness of this type of data when approaching the objectives regarded in this study.

1. Spatiotemporal Variations

The differences in spatial distributions in our results show an opposite distribution for adult and juvenile individuals of hake, we found that juveniles where more abundant in the shelf areas (100-175m) than in the slope whereas adults had a trend to have a higher biomass in the slope areas (175-275m). Distribution maps showed the same results expanding juvenile denser areas from 50 to 250m and adults between 175 and 600m. However, these two size classes yields are very different, juvenile yields are between 3 and 7 times higher than for adults showing also higher differences between areas. Therefore, in a general population view we could consider that adult individuals are distributed with similar biomasses in the slope and shelf habitats whereas juveniles have marked lower biomasses in deeper areas compared to the shelf zone.

Spatial distribution of Hake found in this study is consistent to the results that previous studies found in the same study area (Demestre and Sánchez 1998; Recasens et al. 1998). These studies found a distribution of whole hake population between 50 and 700m depth approximately but with scarce biomasses deeper than 400m. Depth distribution changes between size classes were also found. Juveniles concentrated at depths shallower than 200m whereas adults had wider distributions reaching deeper zones.

The differences found in Hake size class distributions have been associated with the ontogenetic change that this specie has on its diet (Bozzano et al. 1997; Mahe et al. 2007; Recasens et al. 1998). Hake diet is based on crustaceans and fish, but the proportion of these groups in its diet changes throughout hake's life. Recruits (<14.5/17cm depending on the study) have a more diverse diet than adults based on small crustaceans (euphausids, mysids and amphipods) and small benthonic fishes (gobids) (Bozzano et al. 1997). Juvenile hakes (14.5-24.5 / 18-31cm) have a shift towards a more piscivorous diet, based on small benthonic fish (gobids) but small crustaceans (euphausids, mysids and amphipods) are still present. Adult individuals (>25/32cm) have a piscivorous diet based on larger demersal (other hakes) and pelagic (anchovy, sardine) species and some decapods (*Processa sp*, *Solanocera membranacea*). Small, benthonic-associated and low mobility juvenile hake preys determine the distribution of this size class to shelf/shelf-break areas where these type of preys are more abundant (Maynou et al. 2003). Once hake grows its mobility increases due to the biggest size and increased sensitivity to sound and light (Bozzano and Catalán 2002; Lombarte and Popper 1994), this allows adult hakes to have a diet based on larger and more mobile fish species (Recasens et al. 1998) and reach deeper depths. This is consistent with the more stable distribution of Hake 2 throughout all studied areas and the concentration of juveniles in shelf zones (Areas P1, P2, IN1, C2) that we found in our study.

2. Hake Seasonality

Seasonal trends found in our results show a clear seasonality in Hake 5 with a yield peak during the third quarter (July-September) and decreases during the fourth (October-December). For Hake 2 seasonal trends seem to be opposite to Hake 5 as yields decrease from the first to the third quarter, when the lowest annual yields were found. The comparison between normalized and non-normalized data (kg/h) leads to similar consequences as found for spatial analysis. Hake 5 has higher yields than Hake 2 affecting substantially global population trends (Total hake). On the other hand, Hake 2 trends seem to be less important in the whole population due to its lower yields compared with Hake 5.

Juvenile hake seasonal tendencies are associated with recruitment periods. We have to take into account that as we are working with landings data we do not have information about recruits, the smallest size of hake we have is the minimum legal fishing size (20cm). Hake 5 would correspond to individuals of 1-2 years old (Belcari et al. 2006; Mellon-Duval et al. 2010; Recasens et al. 1998). In the Catalan coast, Hake recruitment is found continuously throughout the year although seasonal variability occurs with biomass recruits peaks in spring-summer (Maynou et al. 2003; Recasens et al. 1998). These studies are consistent with our results as we found a main peak of juvenile yields during the third quarter of the year (summer). Juveniles found on this peak would correspond to the recruitment peak of the previous year during the same period. Once the main part of these recruits reach 20cm they can be legally fished so as giving a yield peak for summer in our results. During the fourth quarter juvenile yields decrease again which would be a consequence of the high fishing pressure to which they were subjected on the previous months after entering the fishery.

Adult hake have also been reported to have seasonal variability in their behaviour that has been associated with spawning patterns. In the Mediterranean Hake spawns along all year even if spawning peaks have been reported to occur (Olivar et al. 2003; Recasens et al. 1998). In the Catalan coast, hake spawning peaks have been found during summer-autumn when adult hakes would concentrate on the shelf break to spawn (Recasens et al. 2008; Recasens et al. 1998). We found the highest Hake 2 yields during winter (1st quarter) followed by spring and autumn (2nd and 4th respectively). The aggrupation of adult hakes could make them more vulnerable to fishing activities and therefore increase its yields during spawning season. There is a disparity between results found in the literature and the findings in the present study as the adult hake yield peak we found was on winter and not during spring-autumn as we would expect if our data had recorded hake spawning aggregations. Moreover, our results did not show significant Area + Quarter interactions for Hake 2 as we would expect if the spatial distribution of adults would variate during the year.

There exist some reasons related to the use of trawling fleet as sampling method why we could have found these differences. Spawning aggregations recorded in previous studies (Recasens et al. 1998) were detected with longline hauls as it is a fishing gear more easily used in the continental slope and in rocky substrates, where trawling cannot operate but spawning aggregations are more likely to occur. The spawning aggregations found by Recasens et al. (1998) were mainly found on largest individuals (>60cm for females and >50cm for males) whereas younger adults (30-40cm) where found across the entire studied depth range during the whole year round. Another reason for the differences found in our results is that trawling fleet catch smaller hakes than longlines; our adult hake sizes ranged from 38 to 48cm, which could be a reason why they still do not have a marked spawning aggregation behaviour. It is also possible that the adult peaks we found in autumn and winter are recording the end of spawning aggregations, when adults leave spawning sties to return to their feeding habitats, closer to the shelf and sandy grounds, where they are more vulnerable to trawling fleet.

3. Protected Area Effect

The establishment of the no-take area had an effect on hake yields. Normalized data showed increased yields after the protection started for Hake 2, Hake 5 and Total catches. However, non-normalized data showed opposite trends, a decrease for the period after the establishment of the protected area. In order to disentangle these a priori contradictory results, we have to have a closer look to the data transformation. Once we normalized data we softened the effect of each year mean, that is, we deleted the effect of the global time series trends and we focused on the variations that data has with respect to it. Taking this into account, we can see how non-normalized data is reflecting the global population trends towards decreasing yields (Figure 1). In contrast, normalization allows us to highlight a trend towards an increment even if it is not affecting global decreasing tendency for the moment. Our results also suggested that protection softened Hake 5 seasonality trends (significant interaction of Quarter and Protection factors) and the spatial distribution of Hake 2 (interaction between Area and Protection factors).

The effect of the Roses' protected area inside its boundaries has been proved in previous studies both for the whole community (Balcells et al. 2016) and for Hake population (Recasens et al. 2016). In the case of Hake, global abundances and biomasses were not different when compared the protected zone to an equivalent zone where fishing was allowed (Comparison Area, C2). However the abundance and biomass of Hake recruits were significantly higher in the protected zone (Figure A1). These results confirmed an effect of the protection on Hake recruitment as it had been expected when the protection was planned.

Hake recruitment is not spatially homogeneously distributed, there are some specific zones where high hake recruits concentrations are found over the years, which have been called nursery grounds (Orsi-Relini et al. 1989). These zones would permanently have certain habitat conditions favouring hake recruits development such as food availability and high organic matter (Maynou et al. 2003). Druon et al. (2015) suggested that an abiotic stable environment in terms of temperature and bottom currents are also necessary for the settlement of a hake nursery ground. The establishment of the protected area in Roses aimed at the protection of a nursery ground in order to ensure long term population recruitment.

Our results showed that the protection of recruitment had a positive effect beyond protected area boundaries (increased Hake 5 yields) providing proofs of a spillover effect for these size class. Once recruits inside the protected zone grew, its mobility would have increased expanding to all studied areas. When they reached commercial size classes (Hake 5) fishing yields would have been increased. It is also possible that the increment of recruits inside the protected area had a spillover effect of this size class. However, we could not analyse it as we had no comparable data for non-commercial size classes. Nevertheless, recruit spillover would be less likely than for larger size classes as recruits have a reduced mobility to expand to non-protected areas.

The softened seasonality found after the protection for Hake 5 could also support the spillover explanation. The higher abundances of recruits inside the protected area would provide juvenile supplies to the surrounding areas all year long reducing differences between quarters. Before the protection, the high trawling pressure for juvenile hakes would rapidly reduce the abundances of individuals reaching commercial size classes leading to a yield peak only during the months they enter the fishery. Nevertheless, a good monitoring for recruits and juveniles biomasses inside the protected area would be necessary to establish the relationship between inside and outside seasonality trends.

Higher yields found for Hake 2 size class cannot be explained as spillover effect. Hake 2 individuals are about 4-5 years old (Mellon-Duval et al. 2010; Recasens et al. 1998) and when we carried out this study the protected area had 3 years, therefore, all hake 2 data used in this study correspond to fishes born before the protection started. Hake 2 increased yields are not spatially homogeneous (significant interaction between Area and Protection factors), adult hakes trend to increase more in shelf areas (P1, P2, C2) than for slope areas (S1, S2). It is possible that the increased biomass and density of hake recruits and the whole community (table A2, Balcells et al. 2016) inside the protected area provides increased food supplies for adult hake that would be attracted to these zones increasing its fishing yields. Increased mobility of adult hakes would allow them to move to areas where food supplies are more abundant.

Adult and juvenile movement patterns have been pointed as one of the key factors for the MPA effectiveness (Grüss et al. 2011). For demersal highly mobile species such as Hake (Pontual et al. 2013) the establishment of MPA protecting all life stages of the populations turns to be logistically complicated. Instead, “Targeted MPAs” are designed to protect a zone where fish develop a key life stage such as recruitment or spawning. Modelling studies (Apostolaki et al. 2002) have already studied the benefits of these reserves on hake populations, however, empirical proofs regarding this studies were lacking. Our study provides empirical proofs of positive spillover effect when protecting nursery areas for Hake with the capacity to have a positive effect on adjacent fisheries. However, we have to take into account that due to the reduced time that the protection has been going on we still do not know how the whole hake population will adapt to these changes. It will be necessary to wait at least until 5-6 years of protection or more to see how adult hakes respond to the protection and therefore if spawning patterns change due to the no-take zone establishment. Longer time series are also needed to study if the protection plan is able to revert global declining hake population trends in Roses.

4. VMS/GIS Methodological Considerations

The methodology used in this study provides new tools for the evaluation of MPA/fishing protected zones effects on adjacent fisheries. VMS combined with landings data allowed us to spatiotemporally analyse European Hake population in the Gulf of Roses with results according to previous studies. An important feature of VMS/landings data is the big amount of data they provide, we can analyse species distribution over big areas continuously on time that would be difficult to cover with the scientific logistic capacity. This is an important aspect especially when we are studying highly mobile with long life cycle species such as Hake. This aspect allowed us to study seasonal changes caused by protection that would not have been possible to detect with more punctual sampling methods. In our case we could analyse the protected area effect on big areas surrounding the protected one which supposes a marked difference in the methodology used until the moment to evaluate MPA spillover, commonly based on transects crossing MPA borders or census inside and outside the protected areas (Forcada et al. 2009; Goñi et al. 2008; Harmelin-Vivien et al. 2008; Roberts et al. 2001; Stobart et al. 2009).

However, it is necessary to consider some limitations that VMS/landings data method has. First, we do not have information about non-commercial species or size classes. In our case we did not have information neither for recruits (below minimum commercial size) nor for largest individuals (catched with longline vessels that do not have VMS system) which represent key life stages for population dynamics (recruitment and spawning). Second, we do not have information about population dynamics inside the protected area and therefore, spillover effects or changes detected beyond no-take zone borders are difficult to link with the behaviour of the population inside it. The utilization of our methodology combined with recruits and adults sampling inside and outside the protected zone would allow us to fill some information gaps left by VMS/landings data alone.

CONCLUSIONS

In this work we confirmed the spatial distribution of European Hake populations detected by previous studies in the NW Mediterranean. Juvenile hake distribution trends to be denser at shallower depths (50-250m continental shelf) than adult distribution. Adults are more related to the slope (200-600m) and have less spatial variability between shelf and slope habitats. Seasonal trends for juveniles were also confirmed with a marked peak in summer corresponding to the previous year recruitment peak. However, adult spawning aggregation patterns were not recorded in our data.

We also confirmed a spillover effect for juveniles from the protected area to adjacent zones. Evidences also showed that the protected area establishment softened juvenile seasonality probably caused by a continuous individuals supply from the protected zone. Adult yields also increased and its spatial distribution was homogenized after the protection.

This study provides proofs of a positive effect of the protection on the Roses' Hake fishery and therefore of the potential of this measure to revert the declining trends of the whole fishery during the coming years. However, more time will be needed to observe how Hake population finally adapts to the establishment of the protected area.

These positive results could also be a good feedback for Roses fishermen involved in the co-management plan in order to strengthen their involvement in it and ensure its long term continuity.

Finally, it is important to consider the Roses Hake fishery as a valuable example of fishery management, both for its community involvement and its positive results, with a potential to be exported and adapted to other ports with economically important species exploitation.

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Thank you very much!

APPENDIX

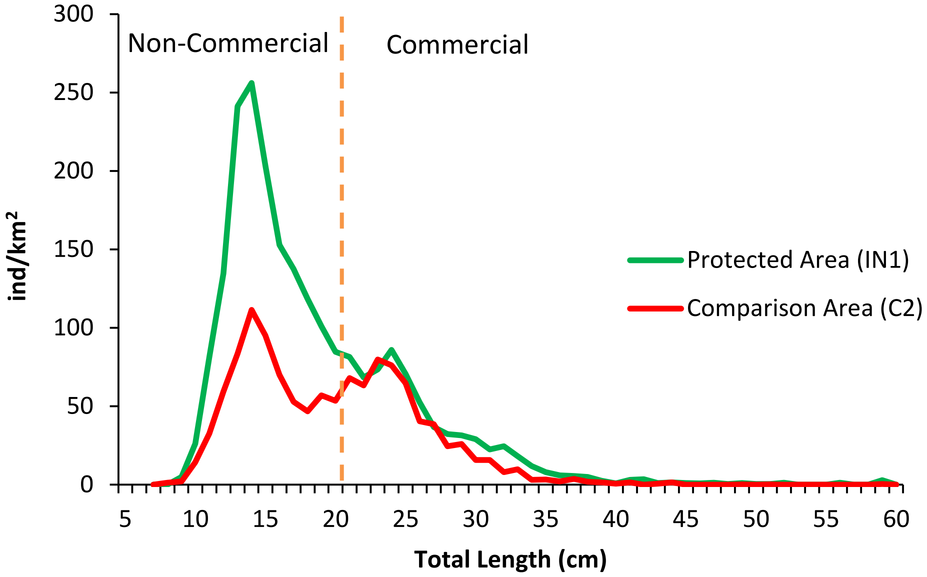

Figure A 1. Hake sizes density distribution for IN1 and C2 areas from March 2015 to January 2016. These results were obtained from previous studies done at the zone (Recasens et al. 2016).

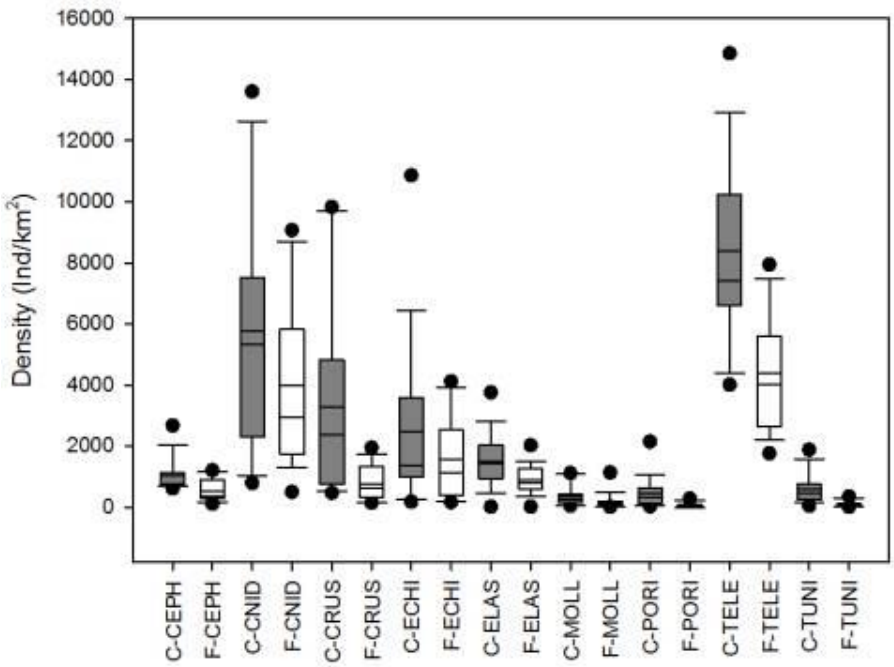

Figure A 2. Boxplot of the density of the main taxonomic groups comparing the protected area IN1 (C) and the comparison area C2 (F). Taxa included are respectively: cephalopoda, cnidaria, crustacea, echinodermata, elasmobrachii, mollusca, porifera, teleostei, and tunicata.

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